# A REVIEW OF THE POTENTIAL HUMAN AND ENVIRONMENTAL HEALTH IMPACTS OF SYNTHETIC MOTOR OILS

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**Joan E. Denton, Ph.D., Director**
**Office of Environmental Health Hazard Assessment**
**California Environmental Protection Agency**

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**PREPARED BY**

Karen Randles
Linda Mazur
Carmen Milanes

**REVIEWED BY**

Dr. George V. Alexeeff, Deputy Director for Scientific Affairs
Dr. David M. Siegel, Chief, Integrated Risk Assessment Branch
Dr. Ned Butler, Staff Toxicologist, Integrated Risk Assessment Branch



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Integrated Risk Assessment Branch

## 1.0 INTRODUCTION

Used oil, generated by its use as a lubricant in automotive vehicles and in industrial operations, constitutes about one third of California's hazardous waste stream (DTSC, 2004). Source reduction – preventing or reducing the amount of waste generated – is the best option for managing waste, according to the waste management hierarchy (CIWMB, 2005a). The amount of used oil generated by the use of lubricating oil in motor vehicles can be reduced by increasing the number of miles driven between oil changes. Today's synthetic lubricants are marketed as providing the consumer with the convenience of extended oil change intervals, in addition to offering better engine performance. To address the potential environmental and human health impacts associated with the use of these synthetic lubricants, the Office of Environmental Health Hazard Assessment (OEHHA) reviewed information on their chemical, physical and toxic properties, along with trends in their use.

## 2.0 AUTOMOTIVE LUBRICANTS

### 2.1 Function of lubricant oils

Lubricating oil serves a number of purposes in the engine. The lubricant protects automotive components by forming a wear-resistant film between moving surfaces, transports various protective chemical additives, and inhibits corrosion. Additives are blended into a lubricant base stock to provide desirable properties such as anti-wear, antioxidant and de-foaming capability and to inhibit corrosion (Totten, 2003). Engine oil performs under harsh conditions inside an engine with its combination of heat and high pressure, combustion activities and generation of chemical residues. In this harsh operating environment, the oil gets dirty, additives and other chemicals break down, and the oil requires regular changing.

### 2.2 Mineral and synthetic lubricant base oils

Lubricant technology has evolved since the mid-1800s, when petroleum-based mineral oils (i.e., refined distillates of petroleum) first replaced animal fats, vegetable oils and marine oils as lubricants. Industrial development during the 19$^{th}$ century created an increased demand for lubricants, but the introduction of the gasoline-powered internal combustion engine is what caused the demand for lubricants to rapidly exceed the supply of natural oils. The refining of crude oil to produce gasoline as fuel for internal combustion engines also provided a source of mineral oil for lubrication purposes (Boyde, 2002).

Automotive lubricant oils are typically 75 to 85 percent base stock (i.e., crude oil-derived product) combined with performance enhancing additives. The base stock may consist of a mineral oil, synthetic oil, or a blend of both. The additives may contain zinc, magnesium, molybdenum, phosphorus, sulfur and bromine compounds (U.S. EPA, 1984). The base oil, in combination with the additives, determines the flow characteristics of the finished lubricant, its volatility and its oxidation stability (sludge and deposit-forming tendency) (Kroschwitz, 2004).

Mineral base oils are manufactured by the distillation of crude oils, followed by further refining of the distillates via separation or other conversion processes (e.g., hydrocracking, hydrogen reforming, and wax isomerization) (Kroschwitz, 2004). These oils are mixtures of paraffins (straight-or branched-chain hydrocarbons), naphthenes (ring forms of paraffins) and aromatics (alkyl benzenes and multi-ring aromatics). Mineral base oils break down in extreme heat and congeal in extreme cold. In addition, mineral oil base stocks contain undesirable impurities such as sulfur, trace metals and carbon residues which can limit the performance capabilities and useful service life of the resulting blended lubricant oils (Mobil, 2005).

Synthetic base oils can be substituted for conventional mineral base oils. Most synthetic motor oils are fabricated by polymerizing short chain hydrocarbon molecules called alpha-olefins into longer chain hydrocarbon polymers called polyalpha-olefins (PAOs). The degree of variation in molecular size, chain length and branching in synthetically produced fluids is much less than occurs in base stocks extracted from crude oil (OECD, 2004). While they appear chemically similar to mineral oils refined from crude oil, PAOs do not contain the impurities or waxes inherent in conventional mineral oils. PAOs constitute the most widely used synthetic motor oil in the U.S. and Europe.

Synthetic lubricant technology allows the products to be designed for particular lubrication applications and, in combination with additives, provides targeted performance. Synthetic lubricants are frequently blended with mineral oil in order to provide desired combinations of properties (Boyde, 2002). Among the advantages for synthetic lubricants over mineral base oils are: low temperature fluidity and thus better cold weather performance; low volatility (i.e., low tendency to evaporate); high-temperature thermal stability (high “viscosity index”); oxidation resistance (of the oil itself); and high natural detergent characteristics (resulting in a cleaner engine with less additive content) (Kroschwitz, 2004). The “green” advantages that accompany the use of synthetic oils include improved fuel economy, decreased oil consumption and extended oil change intervals. A discussion of the environmental impacts of synthetic lubricants is provided in section 4.

## 2.3 Classification of lubricant base oils

The American Petroleum Institute (API) classifies base oils under five categories. These categories help identify base stocks in finished oil formulations to ensure that engine oil performance demands are met (Kramer et al., 2003a, 2000b & 2000c; LePera, 2000; Mobil, 2005).

- ***Group I***: Conventional mineral oils derived from refining selected crude oil fractions. Solvent processing, first used in the 1930s to improve base oil performance, is still used today to produce Group I lubricant stock. While some automotive oils on the market use Group I stocks, they are generally used in less demanding applications.

- ***Group II***: With the development of “hydrotreating” and “hydrocracking” technology, refiners introduced highly refined, low wax base stocks, or oils. While refined to a greater extent than conventional mineral base oils, these hydroprocessed base oils still have performance limitations due to the presence of undesirable impurities. Group II base oils are common in mineral based motor oils currently available on the market and have fair to good performance in lubricating properties.

- ***Group III:*** Group III base oils are also manufactured using the hydrotreatment process but are subjected to higher temperatures or processing times. These highly hydroprocessed, or “non-conventional” oils, have greatly improved oxidation stability and low temperature performance but still contain some undesirable impurities that cannot be removed. These high quality Group III base oils are now widely available in North America because they can be manufactured by most companies making Group II oils.

- ***Group IV:*** API has classified synthetic engine oils made with PAOs as a special class of base stock.

  The term “synthetic” was originally used to refer to Group IV (PAOs) and V (see below) base stocks. With the growth of the PAO market, some base oil manufacturers began manufacturing Group III mineral oils that provide equivalent performance to PAOs, and marketing these as “synthetic” oils. In 1999, a ruling by the National Advertising Division of the Council of Better Business Bureaus broadened the definition of “synthetic lubricants” to include high-performing products made with Group III base stocks.

- ***Group V***: These specialized base oils, with few exceptions, are chemically engineered stocks that do not fall into any of the categories previously mentioned. Typical examples of Group V stocks are esters, polyglycols and silicone.

## 3.0 HUMAN HEALTH IMPACTS

### 3.1 Toxic properties of ***unused*** lubricant oils

Lubricant oils are viscous liquids with low vapor pressures and low volatile organic compound (VOC) content (Boyde, 2002). Thus, exposure to hazardous VOCs via inhalation is expected to be minimal. Both mineral-based and synthetic oils have low acute oral and dermal toxicity (Henry, 1998). The main effects in humans following accidental ingestion of even large quantities of these oils are limited to irritation of the digestive tract, with symptoms of nausea, vomiting and diarrhea. Skin may be mildly or moderately irritated following repeated or prolonged exposure to mineral and synthetic base oils (accidental spills rarely cause problems). Repeated contact can cause defatting of the skin and give rise to signs of irritancy, i.e., redness, inflammation and cracking. These health effects may be attributed to the additive components (e.g., metals and detergents) in lubricant oils.

Unused mineral-based lubricant oil contains very small amounts of polycyclic aromatic hydrocarbons (PAHs) (Wong and Wang, 2001). A number of PAHs are classified as "probably carcinogenic to humans" based on animal evidence (IARC, 2004). Mild hydrotreating (i.e., Group II oils) helps reduce the amounts of carcinogenic PAHs but does not necessarily eliminate them. Increasing the temperature and pressure of hydroprocessing can eliminate carcinogenic compounds. Of the refining steps used in preparing lubricating oil base stocks from petroleum, only effective solvent extraction, severe hydrogenation or exhaustive fuming sulfuric acid treatment appear adequate to eliminate PAHs. Newly synthesized PAOs (Group IV basestocks) do not contain PAHs (Kroschwitz, 2004).

### 3.2 Toxic properties of ***used*** lubricant oils

In addition to the mixture of hydrocarbons and additives present in the formulated product, used crankcase oil contains contaminants that accumulate during use as an engine lubricant. Sources of contamination include additive breakdown products (e.g., barium and zinc); engine "blow-by" (i.e., material which leaks from the engine combustion chamber into the crankcase oil); burnt oil; and metal particles from engine wear, such as arsenic, lead, nickel and cadmium (U.S. EPA, 1984). Numerous other metals are present in used oils such as aluminum, copper, iron, magnesium, silicon and tin; however, they are generally not given much attention due to their low concentrations and low toxicities (ATSDR, 1997).

Motor oils become "enriched" with PAHs during the operation of an engine. These contaminants are fuel combustion products that are transported into the crankcase and concentrate in lubricating oil. In an early study using a 1981 gasoline-powered vehicle, PAHs were not detected in new lubricating oil;

however, concentrations increased rapidly with increased miles driven (Pruell and Quinn, 1988). PAH concentrations (predominantly two- and three-ring compounds) increased until about 4,000 miles and then leveled off. The more toxic five ring PAHs (benzopyrenes) were only detected at 5,800 miles, the longest distance driven. At the end of the study the total PAH concentration in the used oil was 10,300 micrograms per gram (μg/g) or about 1 percent of the oil. A later study compared increasing PAH concentrations in used lubricating oil with increasing distance driven in an old (1990) and new (1996) vehicle (Wong and Wang, 2001). While two-and three-ring PAHs were dominant in oil samples in both vehicles, relatively high concentrations of the more toxic four- and five-ring PAHs were found even at a short driving distance after oil change. After about 2,300 miles, the motor oil in both vehicles contained similar concentrations of total PAHs (1,216-1,295 μg/g).

A third study tested for PAHs in synthetic and mineral-based lubricating oil in a gasoline-powered car run for a short distance (Broz, et al., 2000). Using two analytical methods, PAH levels in the synthetic oil increased from 2.0 and 2.8 μg/g before the run to 51 and 25 μg/g, respectively, after 30 miles. PAH levels in the mineral-based oil increased from 56 and 1.8 μg/g initially to 77 and 63 μg/g, respectively, after 30 miles. The mineral oil was further tested at 6,250 miles, and PAHs levels were measured at 926 and 605 μg/g.

Differences in the type and age of the vehicles used, the analytical method employed, specific PAHs measured, oil sampling intervals, and driving conditions preclude comparing across the three studies. However, despite the different protocols, all three studies consistently show that PAHs accumulate in crankcase oil with increasing miles driven. Because the studies were conducted at least five years ago, and involve only one or two test vehicles each, the results may not be representative of today’s engines and lubricant formulations. Additionally, these studies measure PAH levels in crankcase oil drained at mileage intervals that may be lower than the manufacturer’s recommended oil change intervals for today’s vehicles and lubricants.

As previously stated, the use of highly refined base oils and synthetic oils provides an opportunity for source reduction due to the extended oil change intervals. Depending on the synthetic oil used, oil change intervals can range from 7,500 miles to as high as 25,000 miles (CIWMB, 2005b). Because PAHs have been shown to concentrate in oil during its service life, one of the potential implications of these longer drain intervals is that used synthetic engine oil may contain more PAHs and therefore pose a greater risk to human health. For example, studies indicate there are higher PAH levels in particulate emissions from engines operating with used motor oil compared to fresh lubricant oil (Broz et al., 2000). In this case, people might be exposed via inhalation to elevated levels of PAHs adsorbed to particulates formed from the combustion of lubricant oil and fuel in the cylinders. The recycling of used oil with higher PAH levels to produce fuel oil for combustion may similarly result in higher exposures to PAHs.

Additionally, exposure to PAHs (and other contaminants, notably metals) in used engine oils might occur from dermal contact while changing oil as well as from handling recycled oil used as fuel.

## 4.0 ENVIRONMENTAL IMPACTS

### 4.1 Used motor oil and byproducts in stormwater runoff

Used oil that is leaked, spilled or improperly discarded may enter stormwater runoff and eventually enter into and adversely affect the environmental health of receiving water bodies. Studies monitoring contaminants in runoff consistently report relatively low levels (i.e., ≤ 5 milligrams per liter) of oil and grease entering into surface waters (OEHHA, 2006). It has been reported that petroleum hydrocarbons in urban runoff as well as in aquatic sediment in urban areas are primarily associated with used crankcase oil (Schueler, 1994). However, as reported by OEHHA (2006), the extent to which used motor oil and oil byproducts are polluting stormwater runoff and the ultimate receiving waters is largely unknown. In the case of the highly refined motor oils and synthetic lubricants, the increased PAH levels accumulating due to extended drain intervals (discussed in section 3.2 above) may result in increased used oil-related PAHs entering into stormwater runoff. This may, in turn, result in higher concentrations of PAHs in our nation’s rivers, bays, oceans and sediments.

### 4.2 Achieving better fuel economy and emissions reductions

In a review of the environmental benefits and impacts of engine lubrication, it is stated that optimization of three lubricant parameters – friction reduction, wear reduction and lubricant stability – will lead to positive environmental impacts (Boyde, 2002). Low-viscosity lubricants, which may be made from synthetic or mineral oil blends, are less resistant to flow than conventional lubricants, a property that helps reduce friction and energy losses. Various studies have demonstrated fuel economy improvements ranging from 0.5 to 5 percent with the use of low-viscosity engine lubricants and/or transmission lubricants (U.S. EPA, 2004). The cost savings realized with decreased fuel consumption (it is estimated that fuel savings outweigh the higher lubricant cost), complements a reduction in the amount of greenhouse gas and other contaminant emissions.

Minimizing wear by efficient lubrication prolongs the useful life of an engine, thereby minimizing the consumption of non-renewable resources such as fossil energy and metal ores required for the manufacture and disposal of the machinery itself (Boyde, 2002). In addition, wear of mechanical parts can cause the engine to operate less efficiently; thus wear reduction has a secondary benefit by reducing energy consumption throughout the operating lifetime of the engine. It is expected that lubricant developers will make increasing use of synthetic basefluids which permit optimization of engine performance through chemical design at the molecular level.

A factor influencing the environmental impact of lubricant oils is the stability or lifetime of the lubricant itself. Synthetic oils are generally more resistant to temperature changes, are less volatile than traditional oils, and are not as likely to oxidize in the engine environment. In the case of engine oils, the more stable a lubricant, the less is consumed. If a lubricant can be made to last twice as long, only half as much lubricant will be required, with corresponding reductions in the energy and material requirements for lubricant manufacture. (However, it should be considered that the amount of energy required to manufacture synthetic lubricant oil is estimated to be about three times that of mineral-based lubricant oil.) The increased longevity of synthetic lubrication oils in the engine will also reduce the environmental impact of lubricant disposal (Boyde, 2002).

Synthetic lubricant oils may play a role in the reduction of engine exhaust emissions. Engine lubricating oil has been implicated as a significant parent material in the formation of mobile source particulate matter (PM) emissions (DOE, 2004). Published data suggest that various lubricant properties affect the composition of engine exhaust emissions, and that synthetic lubricating oils (PAOs) yield lower pollutant emissions. A recent study found that diesel engine emissions of nitrogen oxides (NOx) and PM were 8 percent and 19-24 percent lower, respectively, with a full synthetic PAO-based oil compared to mineral-based oil (Gligorijevic, et al., 2006). Several other studies report similar results, with PM emission reductions reported to range from 2 to 50 percent of total PM mass. However, a few studies have reported conflicting results, with PM mass emissions increasing by up to 20 percent in a diesel engine, and up to a factor of 3 in a spark-ignition engine (Froelund and Yilmaz, 2003; Pedersen, et al., 1980). The California Air Resources Board is currently supporting a planned research project that will characterize the significance of lubricating oil in PM formation and determine whether lubricating oil can be formulated to reduce PM emissions from mobile sources (ARB, 2006).

As discussed in section 3.2, as lubricant oils lubricate the engine, they accumulate PAHs. The implication is that the use of longer-life synthetic lubricants may generate particulate emissions with higher concentrations of PAHs (these compounds are generally bound to particulate matter). On the other hand, if the use of synthetic lubricants results in reduced particulate emissions overall (as discussed in the above paragraph), this might offset the potentially greater PAH levels associated with engine particulate emissions.

### 4.3 Biodegradation of lubricant oils

Biodegradation (biologically-mediated breakdown of a chemical to simpler molecules) represents a major means of removal of oils from soil and water. Because of the loss of motor oil to the soil and aquatic environments via engine leaks, spills, and illegal disposal, the biodegradability of lubricant oils is of ecological importance. Laboratory tests are used to provide estimates of the potential for these oils to degrade in the environment. Standardized biodegradability tests (such as those prescribed by the Organisation for Economic Cooperation and Development (OECD) and the Co-ordinating European Council) are intended to allow comparability and reproducibility of results (Eisentraeger, et al., 2002).

Synthetic ester lubricants are degraded more rapidly in soil and in aquatic systems than traditional mineral oil-based products (Haigh, 1995). PAOs show higher biodegradability than mineral oils of equivalent viscosity because of their higher degree of hydrocarbon chain linearity (Boyde, 2002). Within a class of synthetic lubricants, the percent of material biodegraded within a prescribed time period can cover a large range, and different biodegradability tests can give different results for the same lubricant type. For example, biodegradability of PAOs can range from 20 to 80 percent after 21 days using a "primary biodegradability test," which measures the initial transformation from the parent material (Boyde, 2002). Using this same test, biodegradation of mineral-based oils ranged from 10 to 45 percent. Rates and extents of biodegradation vary considerably between laboratory and field situations, largely due to the influence of factors such as temperature, the types and number of microbes, and the availability of oxygen and water (Haigh, 1995). The OECD is currently developing modified test protocols to more accurately reflect conditions in the natural environment.

It should be noted that biodegradation tests are conducted on fresh lubricants, but biodegradability may be altered as a result of the accumulation of metals and other contaminants in crankcase oil during use (Totten, 2003). Tests have shown that used synthetic ester lubricants degrade more slowly than fresh lubricants, although they still biodegrade more rapidly than mineral oil (Eisentraeger, et al., 2002).

## 5.0 IMPACTS ON RECYCLING

In general, to achieve maximum energy conservation and environmental benefit, it is preferable to re-refine used oils into regenerated base oils that can be blended into finished lube oil products compared to combustion for heating value recovery. A recent study found that re-refining used oils saves about 8 percent of the energy content of the used oil compared to combusting the oil for heating purposes (DOE, 2006). As motor oil formulations transition to non-conventional lubricants (i.e., synthetics and other highly refined base oils), it is likely that the quality of the used oil pool available for recycling will improve. Using synthetic oils as feedstock for re-refining will, in turn, yield a better lubricating, more valuable re-refined base oil product. One re-refiner maintains that modern technologies must aim at recovering these partially and completely synthetic components in the “re-raffinates” (residues from extraction processes) to the greatest extent possible (Engelmann, 2006). Another argument for recycling synthetic lubricant base fluids is the fact that their manufacture involves relatively higher process energy requirements than mineral oils (Boyde, 2002).

Re-refining oils can lead to additional environmental benefits because the toxic heavy metals (e.g., zinc, lead, cadmium, and chromium) are extracted from the used oil (DOE, 2006). These metal compounds are solidified and stabilized into asphalt flux, thereby posing minimal environmental risk. If used oils are combusted, however, metals in the flue gases can be released into the atmosphere unless they are captured by air pollution abatement equipment.

## 6.0 TRENDS IN USE

The Energy Information Administration reports that U.S. consumption of lubricants totaled about 2 billion gallons in 2004, with the industrial and transportation sectors consuming about 1 billion gallons each (EIA, 2006). While U.S. demand for lubricants is projected to show only modest growth overall (less than 1 percent), higher quality base stocks and synthetic oils are expected to increase their share of the market as a result of new industry requirements that demand better quality base oils (Freedonia Group, 2006). Globally, the demand for these oils is projected to grow by as much as 20 percent annually from 2004 through 2015 (DOE, 2006). Currently, synthetic and other highly refined lubricant base oils (referred to as non-conventional lube oils) make up less than 4 percent of the total U.S. supply (DOE, 2006). Some industry sources indicate that the high cost of PAOs has limited its market share to about 2 percent of the total lube oil production (Khonsari and Booser, 2004).

Traditional market forces, such as the price of crude oil and supply-and-demand, have historically played important roles in the lubricant market, and will likely continue to do so. Environmental forces, including emission standards and fuel economy requirements, have impacted finished lubricant properties such as sulfur levels, volatility and viscosity. Extended drain intervals appear to be popular with consumers willing to pay for higher priced oils for the convenience of fewer oil changes. Engine manufacturers are adopting increasingly stringent specifications, expanding the market for premium performance oils (Groups III and IV in Europe, and Groups II and III in North America). As more stringent engine oil specifications increase the demand for higher quality base oils, the increased availability of these premium oils in turn promotes the development of even tougher engine oil specifications. The industry anticipates that the availability of significant amounts of high quality base oils globally may eventually lead to global lubricant specifications (Kramer, et al., 2001a and 2001b).

Lubricants will likely continue to evolve towards products with higher purity, lower volatility and longer life. New technologies will enable the use of new feedstocks (such as natural gas) to produce Group III base oils with properties superior to PAOs. Feedstock prices for PAOs will continue to be relatively high, a factor that will likely limit PAO-based lubricants to smaller, specialized markets in North America. In Europe, selected top-tier lubricants requiring PAO will continue to coexist with Group III oils, as they have for years (Kramer, et al., 2003c).

Miller et al. (2005) have developed a process that converts waste plastic (e.g., polyethylene and polyethylene terephthalate, or PET) to lubricating base oil. The process uses pyrolysis, where high-molecular-weight molecules are converted to lower-molecular weight molecules in the lubricant oil range. The product can be further converted to unconventional (i.e., synthetic) base oil quality. Waste plastic is readily available and inexpensive, and its diversion from the waste stream would reduce the growing environmental and political problems associated with landfill disposal.

## 7.0 SUMMARY AND RESEARCH NEEDS

### 7.1 Summary

Synthetic lubricants are specifically designed to possess performance capabilities that are superior to mineral oils. The term “synthetic” applies to a variety of oil formulations, including those containing 100 percent synthetically-derived base stock (most commonly PAOs) or a blend of synthetic base stock with highly refined mineral oils, as well as severely hydroprocessed mineral base oils. Although synthetic lubricant oils are more costly than conventional mineral base oils, they provide the consumer with the convenience of extended oil change intervals. It is projected that the demand for higher quality base oils such as synthetics will continue to increase in light of increasingly stringent engine specifications.

This report characterizes the following toxicity issues and potential environmental and human health impacts associated with the use of these alternative lubricant oils:

- During its working life in an engine, lubricant oil accumulates various contaminants, including carcinogenic polycyclic aromatic hydrocarbons (PAHs), which are transferred from fuel as combustion products. Because oil change intervals are extended with synthetic lubricants, these used oils may contain higher PAH concentrations than used conventional motor oils. Increased PAH levels in synthetic oil drained from vehicles and collected for recycling should be considered and controlled as appropriate when the used oil is burned or re-refined. Further, used synthetic oils that are leaked or spilled into stormwater or other surface runoff may increase used oil-related PAHs in runoff and receiving waters.

- Studies have reported higher PAH levels in particulate emissions from engines operating with used motor oil than with fresh lubricant oil. Because synthetic lubricants are likely to accumulate PAHs to a greater extent due to their extended life in the engine, it is likely that particulate emissions from engines using synthetic oils will have higher concentrations of PAHs.

- PAOs show higher biodegradability than mineral oils of equivalent viscosity because of their higher degree of hydrocarbon chain linearity. However, even within a class of synthetic lubricants, biodegradability ranges widely and various biodegradability tests can give different results for the same lubricant type.

- Performance characteristics of synthetic oils – friction reduction, engine parts wear minimization and lubricant chemical stability -- act to decrease fuel consumption, help the engine to operate more efficiently and reduce greenhouse gas and other contaminant emissions. Recent studies suggest that synthetic lubricants yield lower levels of PM and other pollutants in engine exhaust emissions compared to mineral-based oils.

- As motor oil formulations transition to synthetics and other highly refined base oils, it is likely that the quality of the used oil pool available for recycling will improve. Using this as feedstock for re-refining will, in turn, likely yield a higher-quality, and more valuable re-refined base oil product.

### 7.2 Research needs

Additional data on the following issues will facilitate a better understanding of the human health and environmental consequences of the use of synthetic motor oil as an alternative to mineral-based motor oil:

- *Better characterize/quantify the degree of PAH accumulation in crankcase oil associated with longer mileage intervals between oil changes.*
  As discussed above, the levels of PAHs in crankcase oil will likely relate to levels in vehicle exhaust emissions, in oil that is leaked from vehicles and subsequently carried in runoff, and in the fuel oil produced as a product of used oil recycling and intended for combustion.

- *Better characterize/quantify the pollutant levels in engine exhaust emissions associated with synthetic lubricants, compared to mineral-based lubricants*.

Preliminary research has shown that synthetic lubricating oils yield lower pollutant emissions (e.g., PM and NOx) compared to mineral-based oils; however, the results are equivocal.

- *Better characterize the biodegradability of synthetic lubricants*. Biodegradation tests suggest that synthetic lubricants will biodegrade to a greater extent than mineral-based lubricant oils; however, current test methods may not accurately reflect actual biodegradation processes occurring in the aquatic and terrestrial environments. Furthermore, since tests are conducted on fresh lubricants, they do not analyze for PAHs and metals that accumulate in crankcase oil during use.

- *Investigate the impacts of the potential increase in the use of synthetic oil on used oil collection, recycling, and end-products*.
Should the proportion of synthetic oils in the used oil pool increase, the feasibility of collecting them separately for recycling will need to be determined. Factors to consider include: the higher energy requirements for manufacturing synthetic oils; elevated levels of PAHs, metals and other contaminants in used oil; and alternative processes for re-refining synthetic oils.

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